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Extending the known vertical distribution for the highly adaptive *Triturus macedonicus* (Karaman, 1922)

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Abstract

Current knowledge of the vertical distribution of *Triturus macedonicus* places the species at altitudes up to 2140 m. Herein, we report its presence in the alpine lake Gistova at 2360 m on Mt. Grammos, Greece, thus extending the highest altitudinal point for the species, as well as for the *Triturus* genus. This record showcases the adaptive capacity of the Macedonian newt, which allows it to occupy markedly different environments. More populations may exist at similar or even higher altitudes and their discovery could positively impact conservation efforts.

Key Words

adaptability, alpine, Gistova, Grammos, Macedonian newt, plasticity, vertical distribution

Introduction

Triturus macedonicus (Karaman, 1922) is a newt species endemic to the Balkan Peninsula that belongs to the wider *Triturus cristatus* complex (Wielstra and Arntzen 2016; Wielstra et al. 2019) and its distribution spans through seven countries in the southern part of the European continent: Bosnia & Herzegovina, Montenegro, Serbia, Albania, North Macedonia, Greece (Wielstra and Arntzen 2011) and Bulgaria (Naumov and Tzankov 2008). Previously referred to as *Triturus carnifex macedonicus* and later raised to species level as *Triturus macedonicus* (Arntzen et al. 2007), the Macedonian newt has distinct morphological features from the other *Triturus* species (Arntzen and Wallis 1999; Arntzen 2003; Wielstra et al. 2013). Records to date have placed its vertical distribution at elevations up to 1900 m (Speybroeck et al. 2016), 2000 m (Valakos et al. 2008) and 2140 m on Mt. Smolikas, Greece (Denoël 2004). In the current work, we provide evidence for the presence of *Triturus macedonicus* in Lake Gistova (Fig. 1), the highest alpine lake in Greece at an altitude of 2360 m a.s.l. on Mt. Grammos (Kastoria Prefecture, Greece, 40°21.905'N, 20°47.419'E) (Fig. 2), thus extending the known altitudinal point for the species; as well as for the *Triturus* genus, under which the closely-related species often demonstrate parapatric distributions (Wielstra et al. 2014; Wielstra and Arntzen 2020). In parallel, we confirmed the presence of *Triturus macedonicus* at sea level within the estuaries of the River Pineios (Larissa Prefecture, Greece, 39°52.947'N, 22°43.096'E) at the southern limit of the genus' distribution in Europe (Fig. 3).

There has been only one targeted survey in Lake Gistova, where researchers collected hundreds of alpine newts (*Ichthyosaura alpestris*) for sampling purposes (Papaioannou et al. 2015), but did not record the Macedonian newt. Earlier bibliographical knowledge highlights the presence of *T. macedonicus* on Mt. Grammos when placing a limit on its altitudinal distribution at 1950 m (Sotiropoulos et al. 1995). The question arises whether the present record is a novel discovery of a pre-existing

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Figure 1. *Triturus macedonicus* male in the alpine Lake Gistova.

Figure 2. Alpine lake Gistova, Kastoria, Greece.

population or if a lower population has shifted its dispersal upwards and only recently started occupying this alpine lake. Interestingly, *Triturus* species have been shown to be directly affected by increased temperature (Walther et al. 2002). Studies have also underlined that climate warming has forced a variety of amphibian taxa (Hickling et al. 2006; Chen et al. 2011) including newts of the *Triturus* genus (Tiberti et al. 2021), to shift their distribution towards higher elevations.

Whichever the case may be, the highlight of this record is the impressive adaptive capability of the Macedonian newt, spanning 2360 m of vertical distribution within various environmental conditions. Between sea-level wetlands that suffer scorching summer temperatures and almost permanently frozen alpine lakes, the Macedonian newt can effectively adapt to an impressive range of heterogeneous and even microclimatically fluctuating ecological niches. This is a critical determinant of species

Figure 3. *Triturus macedonicus* female at Pineios Delta, Greece.

survival and an undeniable advantage especially under unstable climatic conditions that can affect hydrological regimens in the Mediterranean Basin (Escoriza and Ben Hassine 2023), including Greece (Panagoulia and Dimou 1995). A recent study conducted by Degani and Meerson (2024) on the newt species *Ommatotriton vittatus*, showed extensive gene expression shifts and transcriptomic remodelling between terrestrial and aquatic stages in a population occupying an extreme habitat, confirming that phenotypic plasticity is the unsurpassed tool that allows amphibians to re-adjust to rapid environmental shifts (Diamond and Martin 2016). Considering the flexible responses that *T. macedonicus* also seems to possess, it may be another great candidate to investigate transcriptomic remodelling in populations occupying the two extreme habitats of its vertical range. Furthering our understanding of these mechanisms can have important implications for conservation and site preservation, because they may act as a buffer against serious threats under climate change (Urban et al. 2014).

Another significant implication of the current work is the possibility of more isolated populations of the Macedonian newt or even other species of the genus existing at higher altitudes. Subject to the available datasets, species distribution modelling approaches can be employed to facilitate the discovery of new populations within their range. A course of action that becomes more imperative after taking into consideration the direct threats through an ever-changing habitat (e.g. climate change, overgrazing, bioaccumulation of agricultural chemicals) and the status of the species. *T. macedonicus* is designated as "Vulnerable" (VU) by IUCN due to a multitude of factors, including aquatic habitat loss (Romano et al. 2009) and is also included in Annex II of the Directive 92/43/EEC which dictates the establishment of special conservation areas (Danelis et al. 2023). A better understanding of its distribution throughout its range would assist in more efficient conservation actions.

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